3. $\frac{f_2}{f_1} = \frac{\sqrt{F_2}}{\sqrt{F_1}}$

$$f_2 = \left(\frac{\sqrt{300\text{ N}}}{\sqrt{150\text{ N}}}\right) 256\text{ Hz}$$

$$f_2 = 362\text{ Hz}$$

4. $\frac{f_2}{f_1} = \frac{\sqrt{D_1}}{\sqrt{D_2}}$

$$\frac{f_{\text{steel}}}{f_{\text{brass}}} = \frac{\sqrt{D_{\text{brass}}}}{\sqrt{D_{\text{steel}}}}$$

$$f_{\text{steel}} = \left(\frac{\sqrt{8.70\times10^3\text{ kg/m}^3}}{\sqrt{7.83\times10^3\text{ kg/m}^3}}\right) 440\text{ Hz}$$

$$f_{\text{steel}} = 463.8\text{ Hz or } 464\text{ Hz}$$

5. (a) $\frac{f_2}{f_1} = \frac{d_1}{d_2}$

$$f_2 = \left(\frac{1.0\text{ mm}}{2.0\text{ mm}}\right) 880\text{ Hz}$$

$$f_2 = 440\text{ Hz}$$

(b) $\frac{f_2}{f_1} = \frac{d_1}{d_2}$

$$f_2 = \left(\frac{1.0\text{ mm}}{0.40\text{ mm}}\right) 880\text{ Hz}$$

$$f_2 = 2200\text{ Hz}$$

### Applying Inquiry Skills

6. (a) Using a sonometer and a sound oscillator, you can determine the frequency of the string. By placing a support under the string, the effective length can be changed. The frequency can then be determined for various lengths.

(b)

| Variable | Sonometer |
|---|---|
| density | • change the masses on the pulley<br>• use different materials (such as copper, brass, steel) |
| diameter | • use different thickness of string |

In each case, the other variables must be kept constant.

## 8.3 MODES OF VIBRATION — QUALITY OF SOUND

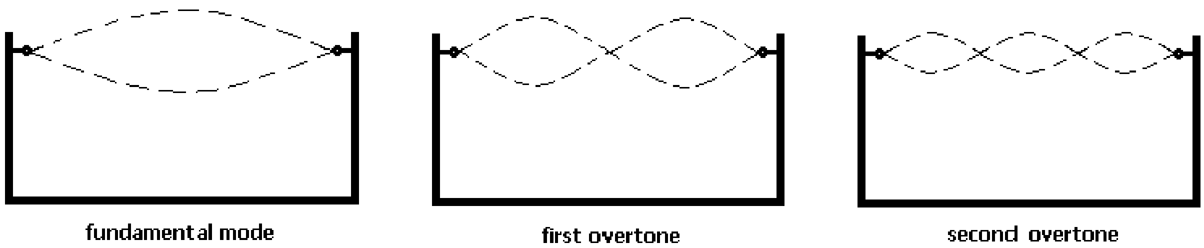
### PRACTICE

**(Page 286)**

### Understanding Concepts

1. The quality of a musical note depends on the number and relative intensity of the overtones produced with the fundamental.
2. (a) the high consonance sound has a higher quality of sound
   (b) the pair of sounds with the ratio 3 : 2 has a higher quality of sound
   (c) the pair of sounds of $f_0$ and $2f_0$

3. (a)




(b) 1st overtone = $2f_0$ = 2(310 Hz) = 620 Hz or $6.2 \times 10^2$ Hz
2nd overtone = $3f_0$ = 3(310 Hz) = 930 Hz or $9.3 \times 10^2$ Hz

(c) 2nd overtone = $\left(\frac{3}{2}\lambda\right)$ = 36 cm
$\lambda = 24$

1st node at $\frac{1}{2}\lambda$ = 12 cm
2nd node at $\lambda$ = 24 cm

## Section 8.3 Questions

**(Page 286)**

### Understanding Concepts

1. (a) $2f_0$ = 2(220 Hz) = 440 Hz
(b) $4f_0$ = 4(220 Hz) = 880 Hz
2. (a) $2f_0$ = 2(440 Hz) = 880 Hz
(b) $3f_0$ = 3(440 Hz) = 1320 Hz
(c) $5f_0$ = 5(440 Hz) = 2200 Hz
3. It is easiest to draw this diagram using metric graph paper. Urge the students to draw the diagram carefully. Refer to **Figure 3**. Assuming that X is the fundamental frequency, then Y is the third harmonic and the addition of X and Y shows a more complex waveform and a higher quality sound.

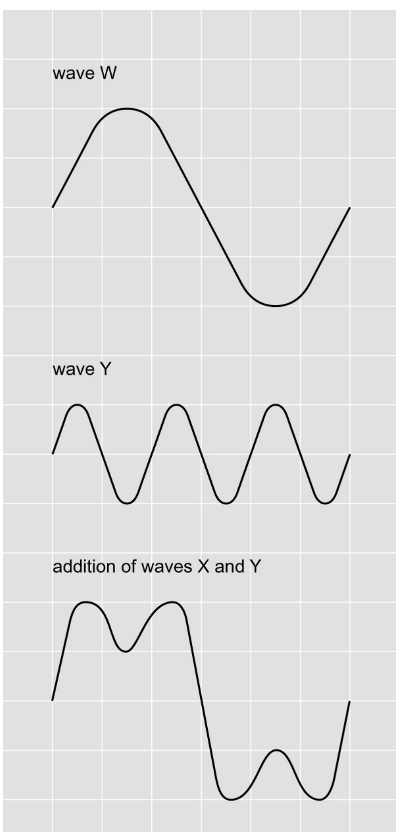



**Figure 3**

4. $3f_0 = 900$ Hz

$$f_0 = \frac{900 \text{ Hz}}{3}$$
$$= 300 \text{ Hz}$$

$2f_0 = 2(300 \text{ Hz}) = 600$ Hz
$4f_0 = 4(300 \text{ Hz}) = 1200$ Hz

## 8.4 RESONANCE IN AIR COLUMNS

### Investigation 8.4.1 Resonance in Closed Air Columns

**(Pages 287–288)**

#### Purpose

The purpose of this investigation is to determine the resonant lengths of a closed air column and the relationship these lengths have to the wavelength of the sound producing the resonance.

#### Question

What are the first three resonant lengths of a closed air column in relationship to the wavelength of the sound producing the resonance?

#### Hypothesis/Prediction

(a) From theoretical considerations of resonance in a closed air column, it is predicted that the first three resonant lengths of a closed air column will be one-quarter, three-quarters and five-quarters of the wavelength of the sound producing the resonance.

#### Design

Vibrating tuning forks were held above the open end of a closed air column of adjustable length. The lengths of the air column where resonance was heard was noted and compared with the wavelength of the sound producing the resonance.

#### Materials

- 80 cm of plastic pipe
- large graduated cylinder
- at least two tuning forks (e.g., 512 Hz and 1024 Hz)
- metre stick
- thermometer

#### Procedure

1. The plastic pipe was inserted into the graduated cylinder that was filled with water (to serve as the closed end).
2. The 512-Hz tuning fork was struck and held above the open pipe. While slowly raising the pipe out of the cylinder, the loud sound denoting resonance was noted. The length of the pipe from the water level to the top of the pipe was measured and recorded in **Table 1**.
3. The pipe was raised higher out of the water until the second point of resonance was noted and recorded. Similarly, the third resonant length was noted and recorded.
4. A second tuning fork of frequency 1024 Hz was used in an identical way and the first three resonant lengths were noted and recorded in Table 1.
5. Also noted in Table 1 are the lengths of the resonant columns in terms of wavelengths of the sound wave producing the resonance. For these calculations, see Analysis below.

#### Observations

Resonance was noted for both tuning forks at each of the first three resonant lengths. The intensity of the sound at these lengths was notably louder. The resonant lengths are recorded in **Table 1**.

The air temperature was measured and recorded as 20°C.